1a) We will study balanced forces and its relationship to the Rossby number using the rotating tank. We rotate a bucket filled with water with a hole in the middle. Water begins to drain out of the bucket, but the water spirals in cyclonically due to conservation of angular momentum. Approximate the Rossby number at three different radii: near the outer edge of the bucket, about halfway to the center, and near the center. Note that the Coriolis parameter for the rotating tank is $f = 2\Omega$, where $\Omega$ here is the angular velocity of the rotating table.

1b) Based on your Rossby numbers, what balanced flow (geostrophic, gradient, cyclostrophic) would be appropriate at each of the radii? What does this imply about the predominate balance of forces at each radii?

1c) Consider the following winds in a strong hurricane at 20°N:

<table>
<thead>
<tr>
<th>Radius from Hurricane Center (km)</th>
<th>Wind Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>500</td>
<td>25</td>
</tr>
<tr>
<td>1000</td>
<td>5</td>
</tr>
</tbody>
</table>

Calculate the Rossby number at each of the radii. Remember to revert back to the definition of the Coriolis parameter for Earth.

1d) Relate your answers from part a) and b) to the hurricane, i.e. how does the balanced flow change as an air parcel spirals toward the center of a hurricane?

2) Explain why it is impossible to have a high pressure area with counterclockwise geostrophic wind or a low pressure area with clockwise geostrophic wind in the Northern Hemisphere. 
(Hint: Draw a sketch of the forces.)

3a) We will study the ratio between the gradient and cyclostrophic wind in this problem. Eliminate the pressure gradient force term in the gradient wind equation by using the cyclostrophic wind equation.

3b) Solve for the gradient wind using the quadratic formula. Keep only the positive root. 
(Hint: Your answer should be a function of $f$, $R_{curv}$, and the cyclostrophic wind.)

3c) Form a ratio between the gradient wind and the cyclostrophic wind by dividing your expression in part b) by the cyclostrophic wind.

3d) For a cyclonic low pressure in the Northern Hemisphere, prove that the gradient wind must always be less than the cyclostrophic wind, i.e. the ratio you formed in part c) must always be $< 1$. (Hint: Get your ratio in to the form $-x + \sqrt{x^2 + 1}$ and use the fact that $\sqrt{x^2 + 1} < (x + 1)$, where $x$ is an arbitrary expression.)
3e) Explain physically in terms of force balances why the gradient wind must be less than the cyclostrophic wind for a cyclonic low pressure in the Northern Hemisphere.

4a) The mean temperature in the layer between 750 and 500 hPa decreases eastward by 3°C per 100 km. If the 750 hPa geostrophic wind is from the southeast at 20 m s\(^{-1}\), what is the geostrophic wind speed and direction at 500 hPa? Let \( f = 10^{-4} \) s\(^{-1}\).

4b) What is the mean temperature advection in the 750 to 500 hPa layer in part a)?